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A 40-Year Performance Assessment of Prestressed Concrete (PC) I-Girder Bridges In Michigan

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ABSTRACT

Durability performance of Michigan's PC bridges is investigated. The performance investigation is based on detailed inspection of twenty bridges and inspection data of other bridges. Utilizing the data generated from performance evaluation a management procedure is proposed. The primary expectation from the management procedure is to identify the PC I-girders vulnerable to end deterioration and tendon corrosion. The procedure is based on analysis of the bridge inventory and condition data, a multi-state survey in the US, and a detailed field inspection of twenty highway bridges. Finite element modeling of a PC I-girder is also performed to evaluate the causes of observed beam-end distress. The stress formation at the end zones and cracking potential are studied. The discrete beam analysis identifies the effects of prestressing loads. Protection and repair techniques corresponding to distress condition states are recommended. Currently, in Michigan bridges are monitored based on visual inspections performed every two years. The rating is a condition state and assigned for each of the bridge components. Utilizing the field inspection observations, twelve condition states are established common to the PC I-girder bridges. The maintenance and repair activity required for each condition state is identified.

Key Words
Prestressed Concrete, Highway Bridge, Monitoring, Preventive Maintenance, Rehabilitation, and Bridge Inspection

INTRODUCTION

In the US the first PC highway bridge was constructed in 1951 in Pennsylvania, and in 1958 in Michigan. There are a total of 2632 PC bridges in Michigan with design types of I-beam, box beam or spread beam. A predominant number of the PC I-girder bridges (345 out of a total of 699) were constructed in Michigan between 1960 and 1970. The histogram of PC and PC I-girder bridges in Michigan is shown in Figure 1. General characteristics of these bridges are shown in Figure 2 as pie charts describing structural and operational parameters. Prestressed concrete girders are now the choice in freeways bridges subjected to severe exposure conditions with I-girders being the most preferred type. Consequently, there are quite a few PC I-girder bridges in Michigan on the National Highway System routes, which are subjected substantial truck traffic. The bridges in the 1960's and 1970's until 1975 were designed for 33-ton truck. Since 1975 the design load has been 41-ton truck. Most recently, some states use HS25 design vehicle, which represents a 25% increase in loading over the standard HS20-44 truck for a total gross vehicle weight of 90,000 lb (*1*).

Other aspects of the PC I-girder bridge design have evolved since the fifties. In earlier designs the girders were simply supported on elastomeric bearing pads with an unshored composite concrete deck having expansion joints between each span. More recently the deck is cast continuously with the approach pads and monolithically with sizable diaphragms over the piers and the abutments. The girder ends are waxed during the casting of the diaphragms, assuming that rotational freedom is provided. On the deck surface, control joints are cut at the inflection point locations. The primary reason for the continuous deck was to eliminate the leaky joint in order to provide a roof over the beam-ends and pier caps for protection from heavy applications of deicing salts.

An earlier study focusing on the condition of Michigan's PC bridges revealed that while most were in fair or better than fair condition, older structures were beginning to show signs of deterioration at the ends of the PC beams (*2*). Newer structures (less than 20 years old) utilize joint details that help to deter the deterioration as described above. Major concerns observed with older structures included the corrosion of prestressing strands and high chloride concentrations in concrete. It was reported that the deterioration level was influenced by the location of the bridge, traffic volumes, load limits, and de-icing salt usage. The study brought out the need for clear guidelines in appraising the vulnerability of the PC I-girders.

RESEARCH OBJECTIVES

The specific goal of this research is to propose a management procedure for PC I-girder bridges and to develop/recommend protection and repair techniques corresponding to each state of distress. The primary expectation from the management procedure is to identify the PC I-girders vulnerable to end deterioration and tendon corrosion. The procedure is being based on extensive analysis of the bridge inventory and condition data, a multi-state survey in the US to learn about the experience of other State Highway Agencies, and the detailed field inspection of twenty highway bridges.

The protection/repair procedure recommendations are also one of the research goals. These procedures will be based on what is reported in the literature and analytical finite element (FE) studies of a typical PC I-girder bridge. Additionally, experimental evaluation is underway for the repair of girders with extensive delamination considering the applicability of various patch materials for vertical and overhead repairs.

The long-term bridge management goal in Michigan is to utilize tools and procedures for a network of bridges in planning and scheduling maintenance and repair activities. In network management tools, analytical models are incorporated for predicting service life of bridge components specifically with respect to corrosion-initiated distress (*3*). Issues related to social and political priorities, traffic control, and re-routing issues necessitate that the repair and maintenance activities are performed on highway corridors: In this approach repair and maintenance are performed only on the bridges along and on the corridors planned for that activity season. The objective of the bridge repair and maintenance activities is to improve the condition of all the components to above "satisfactory". Keeping this reality in mind, the management procedure will include a table with maintenance repair techniques for each condition state category.

METHODOLOGY

The research was conducted in a systematic manner. Using the inventory database, "Pontis"(*4*), provided by MDOT all of the PC I-girder bridges were identified and classified according to their attributes. Next, 20 bridges were selected as a statistical representative group, and a detailed field inspection was conducted on the PC I-girders of each bridge. Also, a national survey was sent to all the State Highway Agencies to obtain their observations and practices of PC I-girder ends. Once the field data was gathered, it was analyzed to identify and document the common distress states of PC I-girder ends. In conjunction, a statistical analysis was performed on the PC I-bridge inventory and inspection data to identify causes and progression of distress. To verify the cause of distress, analytical investigations were conducted using finite element analysis. Then maintenance, repair, and upgrade techniques were identified to reduce beam-end distress. Lastly, an experimental assessment was conducted using a selected number of repair techniques.

Multi-state survey in the US

To define progress other states are making in the area of prestressed I-beam end inspection, preventive maintenance, and repair the research team developed, issued, and reviewed the feedback from a technical survey. With well-structured questions and an adequate response, a survey can be an effective tool for quickly interviewing a wide range or set group of respondents. The use of surveys is not a new concept in research. The durability and deterioration of prestressed concrete bridges has been investigated using surveys to state transportation departments in at least three past projects (*5*,*6*,*7*).

Objectives of the survey included determining practices that are used for inspecting and repairing prestressed concrete I-beam ends, and identifying reports relating to the evaluation or repair of prestressed concrete I-beam ends. Five objectives were identified when preparing questions for the survey: (1) Obtain a nationwide response, (2) Identify contacts for specialized areas of bridge engineering, (3) Locate potential sources of overall bridge condition and detailed beam-end survey data, (4) Determine what practices are being used for evaluating and repairing prestressed concrete I-beam ends and (5) Identify reports relating to the evaluation or repair of prestressed concrete I-beam ends.

A survey return rate of 40 percent was achieved with 20 states responding. Over 70 percent of the respondents indicated that they use some unique internal software for management of their state's bridge structural/safety data. All respondents indicated they do not gather specific inspection data on prestressed concrete beam-end conditions. It was unclear from the survey responses if any states are using existing documentation (reports, etc.) to aid in the preventive maintenance of prestressed concrete I-beams. While most states have not repaired prestressed I-beams for end deterioration, roughly 50 percent of the respondents indicated that DOT specifications would be used in the rehabilitation of prestressed concrete I-beam ends.

DATA ANALYSES

Pontis Data

Bridge management in Michigan is performed using a relational database integrated under "Pontis". According to the inventory data, there are 5902 bridges in the National Highway System under the jurisdiction of Michigan's Department of Transportation (MDOT). Out of this total 2632 are prestressed concrete with design types of I-girder, box girder or spread box girder of which, 699 are PC I-girder bridges. PC box girders are designed for spans up to 43 meters. AASHTO type PC I-girders are designed for spans up to 32 meters, and the Wisconsin Type I-girder with a depth of 1800 mm can achieve a span of 46 meters using 48 MPa concrete.

Bridge condition is documented by visual inspections and is performed on each bridge component. The Pontis inspection condition rating is assigned for each of the inspected components and is based on a scale of one (poor) to four (very good). Specifically for PC I-girder bridges, Pontis rating is provided for the barriers, expansion joints, deck, stringers, diaphragms, bearings, piers, abutments and the drainage system. Inspection comments prepared by MDOT inspectors are also documented in Pontis. A total of 499 PC I-girder bridge inspection reports were analyzed by reviewing each record and counting the occurrences of cracking, corrosion or rust, delamination and spalling reported on the girders. Data processing revealed that the delamination parameter is redundant since this phenomenon is always accompanied with the spalling. Consequently, the analysis is focused on inspector reports containing the terms of rusting and spalling. The PC-I bridges that are found to exhibit at least signs of corrosion as determined from inspectors comments are shown on a histogram in Figure 3 together with the totals.

One hypothesis was the PC I-girder end vulnerability is due to the presence of early age cracking. These cracks appear as early as during manufacturing at the pre-cast plant after strand release. In order to see the influence of cracking on the beams, 499 inspection reports were re-analyzed with respect to numbers of bridges with beams with cracks and without cracks. The count of inspector reports indicating cracked prestressed concrete I-beams was 263, leaving 236 records for the bridges with uncracked beams. The review of inspector comments also showed 109 bridge beam notes that have "cracks and rusting or corrosion," whereas 40 comments were found for the beams that have “corrosion or rusting” documented but with no mention of cracking. When both “rusting or corrosion” and “spalling” are searched in the inspector comments, the reported numbers with cracked beams was 87, and 23 for the beams with no mention of cracks. The counts of cracked and uncracked prestressed concrete I-beams showing rust against the year constructed are shown in Table 1.

Although the accuracy of the statistics based on the states reported by the bridge inspectors can be questioned, Table 1 still depicts some important observations. Taking beam corrosion as the primary parameter, the ratio of bridges with prestressed concrete I-beams showing signs of corrosion to the total number of cracked and uncracked beams can document the importance of cracking in beam durability. The ratio of number of bridges with observed signs of corrosion to the total number of bridges with cracked beams is 0.41 whereas this ratio decreases to 0.17 for the bridges with beams where inspectors did not indicate presence of cracks.

Field inspection data

The inventory data of the inspected bridges are shown in Table 2. The purpose of the inspection was to select a representative group of bridges in order to identify fleet specific distress states. Thus, the list contains bridges at different ages 2-40 years and at various condition states.

The inspection goal was to document precise beam-end condition and thus very detailed information on location, size and orientation of cracks, delamination and spalling was collected. The field investigation data was collected on template forms prepared for each bridge. The templates shown in Figure 4-c were prepared for every beam on a bridge.

As an example of the template use, consider the beam-end condition of one of the inspected bridges (bridge ID 06111-S110) shown at Figure 4-a. The typical beam-end condition of this bridge is shown on Figures 4-b and 4-d. The difference in the conditions of two beam-ends is due to variation in restrains at the beam-ends, bearings and the deck condition. On the template form, Figure 4-c, all faces of the beam-end were inspected and all signs of deterioration were documented on the form. Cracks were drawn to a rough approximation with respect to their length, location, and orientation. Corrosion, delamination, spall, water stain, efflorescence, and exposed rebar were carefully sketched onto the form to show approximate areas and locations. The data presented on all the field investigation forms is qualitative information, therefore a custom made Microsoft Access database was created to transform that data into quantitative information for analysis.

The hypothesis of beam-end deterioration for prestressed concrete I-beams was that cracks in the early part of a bridge’s life result in more rapid regression of rebar and tendon corrosion. To test this hypothesis an analysis was conducted on the field inspection information organized in the Microsoft Access database. There were 750 inspected beam-ends each of which was described by the condition on its four faces. These faces were North or South, East or West, Under and Rear-end faces of all 20 bridges.

Table 3 summarizes the results of the field inspection data. The results are grouped with respect to the year built and presented as percentage to the total number of inspected beam-ends. Cracks, corrosion, delamination and spalling are the deterioration mechanisms taken into account in the analysis. As was expected, the older structures exhibit more deterioration than newer structures. Two to seven year old beam-ends were found to be in good condition, although these bridges already display some beam-end problems, such as vertical and diagonal cracks, and horizontal cracks along the flange.

Table 3 also documents the progression of deterioration on beam-ends. As seen, bridges that are older show more delaminated and spalled beam-ends, while younger bridges show beam-ends in cracked or cracked & corroded states.

ANALYTICAL ANALYSES OF CRACKING POTENTIAL OF A PC I-GIRDER

The field investigation revealed that beam-end distress progresses rapidly if cracking is present. Beam-end cracking was observed even in new girders in the plant and on girders of recently built bridges. A 3-D finite element (FE) model of AASHTO PC I-girder was utilized to identify the causes of the cracks appearing in the mid-web and on the transition zone between web and bottom flange, Figure 5-a. A simply supported I-girder, AASHTO Type-III, with a length of 49 feet was modeled using solid elements. Pre-and post-processing was performed by utilizing HyperMesh v5.0, a commercial software package, for preparing the FE mesh. ABAQUS, a finite element analysis program, was employed to solve for the desired outcomes such as displacements, stresses, etc. The results, given in Figure 5-b, 5-c, and 5–d as stress contours, focus on the beam-end for the half of the beam cut along the x-z plane.

Positive values in Figure 5-b and 5-d refer to tensile stresses, whereas the positive and negative signs indicate the direction of the shear stresses in Figure 5-c.

Axial stresses in x direction, shown in Figure 5-b, clearly show that the axial and flexural stresses gradually develop within a length termed as the transfer length. As seen in Figure 5-b, the prestressing force is fully transferred to the concrete member between 27.50 in and 34.00 in, after which the axial compressive stresses stay constant. This discrepancy in prestressing force transfer results in shear stresses by generating varying flexural stresses along the transfer length at the beam-end. Concrete material with a compressive strength of 5 ksi and an elasticity modulus of 4,300 ksi is defined in the FE model. A cracking strength of 0.53 ksi is obtained by the formula of $7.5\sqrt{fc'}$ for normal weight concrete (*8*). It can be construed that cracks on the transition zone between web and bottom flange are due to the shear stresses developed on xz plane at locations where the stresses are around 0.82 ksi, as seen in Figure 5-a and 5-c. It should be noted that the absolute values are of importance for the assessment of cracking potential in Figure 5-c. The analysis also revealed that mid-web cracks are due to the tensile stresses generated by Poisson's effect in z direction near the beam-end, as shown in Figure 5-a and 5-d.

Elements under uniaxial loading show lateral deformation due to Poisson's effect. When lateral reinforcement is provided, it generates passive pressure around the concrete inside the reinforcement by preventing the lateral deformations (*9*). Therefore core concrete is loaded triaxial instead of uniaxial. As a result, member strength and shear capacity are increased. For beam-end stresses within transfer length due to prestressing transfer, if adequate reinforcement is supplied, the shear capacity of the member will be improved. Member end confinement is recommended also in the literature and the codes (8,9) as a remedy for bursting cracking. In order to eliminate or reduce the cracking potential at the girder ends, the stirrups especially within the bottom flange should be closed to provide lateral confinement. Welded wire mesh reinforcement may also be used as confinement steel.

PROTECTION AND REPAIR TECHNIQUES

As described earlier the state highway agency schedules maintenance and repairs on the bridges along selected corridors. The bridges with safety-associated distresses that are not on the repair schedules are often dealt with temporary shoring and strengthening procedures until the corridor bridges are scheduled. In order to assist the highway agency in these corridor projects, Table 4 is generated which provides a link between girder-end distress and common repair and maintenance procedures specific to that distress. Utilizing the field inspection observations 12 condition states are established common to the PC-I girder bridge fleet. The maintenance and repair activity required for each condition state is identified as shown in the Table 4. Also shown is the relationship between the condition states developed and specified by FHWA for safety assessment of bridge. Few photos of some common condition states observed during the inspections are shown in Figures 6-a and 6-b. Here especially interesting is hairline and map cracking observed on girders, perhaps, as a result of precast plant procedures. Also, interesting is nonfunctional bearing pads which is often assumed a maintenance free component.

For girders in the most severe condition state, Michigan has developed an overcasting repair procedure for prestressed concrete I-beams with end distress (*10*). Prior to encasing the beam end, the Michigan procedure specifies removal of deteriorated web and flange concrete. The overcast section on the beam-end is also integrated with a new diaphragm. Repair concrete for this design is MDOT Grade D polymer (latex) modified concrete. MDOT plans were prepared detailing an end repair method for prestressed concrete I-beams with and without end blocks. This repair technique was executed in 1999 in Lower Michigan (*11*). Although numerous problems were encountered in the field repairs, they appeared to be attributed to contractor/engineer miscommunication and not necessarily to the design details. According to MDOT, the cost of repairing prestressed concrete I-beam ends using this procedure was found to be 35 to 70 percent of full-replacement cost.

CONCLUSIONS AND RECOMMENDATIONS

Bridge condition assessment is based on the visual inspections performed every two years. At this time in Michigan, two independent instruments are used in defining the condition state. The first instrument is described in the Michigan Pontis Bridge Inspection Manual and primarily intended for fleet management tasks such as scheduling preventive maintenance. The second instrument is described in the Michigan Structure Inventory and Appraisal Coding Guide, used for National Bridge Inventory System (NBIS inspections) with a primary purpose of safety assessment. Pontis has defined pre-determined assessment criteria for an inspector to follow for assigning a condition state and potential feasible actions. In contrast, the Michigan Structure Inventory and Appraisal Coding Guide allows for greater latitude in assigning condition ratings to a structural element. In a Federal Highway Agency manual (Manual 90) for the training of bridge inspectors, it is required that inspectors rate bridge elements, including prestressed concrete I-beams, as a whole, rather than allowing individual locations of distress to lower an element's rating. Inspectors are expected to modify the condition rating accordingly if an isolated distress (possibly beam-end deterioration) influences the load carrying capacity or serviceability of the element. The NBIS inspection condition rating for a superstructure element, such as a prestressed concrete I-girder, is based on a scale of 0 to 9. The condition scale does not provide a uniform damage severity classification for various concrete distresses and assessment is left to the judgment of the bridge inspector.

The contribution here is in the utilization and classification of the inspection data. First contribution is in the PC I-girder vulnerability assessment based on the distress observed at the girder ends. The reason for the vulnerability assessment to be based on the girder-end distress is that the ends over bearings are directly in the load path. Additionally, a cursory review of the inspection reports showed that other than end deterioration high load hits were also common damages in the girders. The rapid progression of end distresses is due to expansion joint and/or drainage system failure. With joint failure, surface water together with dissolved deicing salts drains over the girder ends. Deicing salts with sufficient time reach and initiate corrosion of the reinforcement and the tendons especially when girder-ends are cracked. Upon performing the inspection, reviewing the inspection data consisting of 828 girder-ends and an equal number of bearings and sole plates, a pattern of deterioration was identified and a preliminary vulnerability assessment measure has been developed. The measure is based on the state of girder-end cracking in excess of 0.01 inch, expansion joint condition, functionality of the bearing pads and the state of corrosion of the sole-plate. The vulnerability can directly be determined from the bi-annual visual inspection reports. Five of the bridges inspected were of more recent vintage incorporating the continuous joint detail cast monolithically with the diaphragm and deck. The behavior of newer bridges is significantly different due to the lack of water infiltration (no leaky joint) and lack of subsequent restraint at the pier and abutment, reduce sole plate and tearing corrosion. The field survey of twenty PC I-beam bridges included detailed visual inspection of the overall I-beam structure condition, including end deterioration for each I-beam. Beam-ends aging from two to ten years old were in good condition, while older structures exhibit a greater amount of deterioration. Joint details in this bridge group vary with age and are likely the source point of deterioration (high volumes of de-icing salts through leaky joints cause end deterioration of the I-beams). There is also a need to include end condition assessment in the inspection procedure. This will allow for inspectors to rate the condition and properly assign a protective strategy prior to severe deterioration.

Currently detailed analytical models of PC I-girder bridges of typical configurations are developing for a clear understanding of the bridge response under the complexities and the variations of the structural system. Using the models, a three dimensional FE analysis will be conducted in order to evaluate the restraints imposed on the girders due to the continuous deck and diaphragms. The FE model also includes the concrete barriers that are located on both sides of the deck surface and are often cast with anchor rebars going into the deck.

Other research is dealing with obtaining an international perspective on prestressed concrete I-beam end deterioration issues and repair techniques such that protective strategies can be evaluated for effectiveness and feasibility for use.

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LIST OF TABLES

LIST OF FIGURES

TABLE 1 Observed Corrosion Distress in Cracked and Uncracked PC I-Girders Constructed since 1959

Year Built	Number of PC I-girder Bridges	Number of Bridges	
		Rust Stained & Cracked I-girders	Uncracked but Stained Girders
1959-1968	332	93	26
1969-1978	71	12	6
1979-1988	141	3	1
1989-1997	124	1	7

TABLE 2 Inspected Prestressed Concrete I-Beam Bridges

Bridge ID	Year Built	No. of Spans	Length, (m)	Max Span Length, (m)	No. of Girders	ADTT [i] On	ADTT [i] Under	Skew (Degree)
41029 S230	1972	3	35.5	18.0	24	2275	N.A[ii].	3
41029 S163	1964	3	38.4	19.2	24	2295	N.A.	3
41029 S164	1964	3	38.4	19.2	24	2295	0	3
41027 S060	1963	3	42.0	18.0	36	2725	0	1
41025 S070	1961	4	64.3	21.3	24	337	3200	0
67016 S090	1984	1	33.8	33.8	6	518	621	0
67016 S100	1984	1	33.0	33.0	7	518	518	0
53034 S050	1986	4	93.2	33.0	24	N/A	N.A.	0
83033 S060	1997	1	44.5	44.5	8	N/A	N.A.	13
83033 S050	1998	2	72.4	38.0	8	N/A	N.A.	23
25042 S128	1967	4	64.0	20.0	16	576	8040	20
25042 S123	1969	4	64.0	20.0	22	3000	8040	20
25042 S124	1969	4	64.0	20.0	22	3000	N.A.	20
25042 S127	1969	4	64.0	20.0	16	576	8040	20
06111 S110	1968	6	116.0	22.3	54	324	1600	27
25132 S340	1971	4	53.4	17.9	24	855	492	12
29011 S030	1961	3	34.7	13.4	27	700	57	2
06111 S040	1968	3	34.0	15.0	18	950	273	0
06111 S050	1968	3	47.5	16.7	15	N/A	800	38
06111 S060	1968	3	47.5	16.6	15	N/A	800	37

[i] Average Daily Truck Traffic
[ii] Not Available

TABLE 3 Frequency of Cracks and Corrosion in Primary Faces on Inspected Bridges with Year Built

Year Built	No. of Girders	Total No. of Beam-ends Inspected	Beam-ends with No Cracks & No Corrosion (%)	Beam-ends with Cracks (%)	Beam-ends with Cracks & Corrosion (%)	Beam-ends with Delamination (%)	Beam-ends with Spall (%)
1961	51	101	0	0	18	25	56
1963	36	71	0	0	7	12	81
1964	48	94	0	10	17	26	47
1968	102	157	0	10	18	24	48
1969	76	147	0	14	24	21	41
1971	24	48	4	4	18	14	61
1972	24	48	0	58	6	10	25
1984	13	25	0	41	16	31	12
1986	24	27	0	19	52	22	7
1997	8	16	0	94	6	0	0
1998	8	16	13	81	6	0	0
Total	414	750	0	17	18	20	44

TABLE 4 Rating and Condition States with Repair and Protective Maintenance (PM) Techniques

Rating and Condition State	FHWA Condition Rating and Description	PM / Repair Technique
1-No cracks observed, no staining	**9 -** Excellent Condition	None
2 -Efflorence, waterstains, and/or corrosion	**7 -** Good Condition	None
3 - Hairline Cracks. They can be horizontal, vertical, and/or diagonal		Surface Insulating Methods *(Penetrating, Surface, Sealers, Coatings, and Crack Sealants)*
4 -Map Cracks		Surface Insulating Methods Electron Control Methods *(Surface Applied Corrosion Inhibitors, Sacrificial Anodes, Impressed Cathodic Protection)*
5-Hairline Cracks with efflorence, waterstains, and/or corrosion with a horizontal crack propagating from the sole		Surface Insulating Methods Electron Control Methods
6 -Cracked and Deformed Neoprene Pad, probably non-functional	**6 -** Satisfactory Condition	Electron Control Methods Surface Insulating Methods Reinforcement Surface Preparation *(Epoxies, Liquid Corrosion Inhibitors, Zinc-rich Paint)*
7 -Moderate Cracks		
8 -Moderate Cracks with efflorence, waterstains, and/or corrosion		Secondary Framing Modification *(Replace Diaphragms)* Surface Sealers Re-alkalization, Chloride Ion Extraction, Concrete Surface Preparation *(Compressed Air, High Pressure Water, Grit and Sand Blasting, Scrabbling, Wire Brushing)* Electron Control Methods
9 -Major Cracks with efflorence, waterstains, and/or corrosion		Support Member Modification *(New Haunch and New Bearing)* Primary Framing Modification *(Supplemental Beam, Full Beam Replacement)*, Environment Modification Methods *(Re-Alkalization, Chloride Ion Extraction, DC Current Impressed, and Surface Applied Barriers)*
10 -Delamination with Moderate and/or Major Cracks	**5 -**Fair Condition	Deck Modifications *(Joint Repair, New Joint, Overlay, New CLL Deck)* Primary Framing Modification Electron Control Methods Partial Depth Beam Repair *(Concrete Removal, Concrete Surface Preparation, Reinforcement Cleaning, Reinforcement Surface Preparation)*
11 -Spall, Delamination, Corrosion, and Cracks		
12 -Spall, Exposed Reinforcement and Corrosion	**4 –**Poor Condition	Replacement of the superstructure and substructure elements

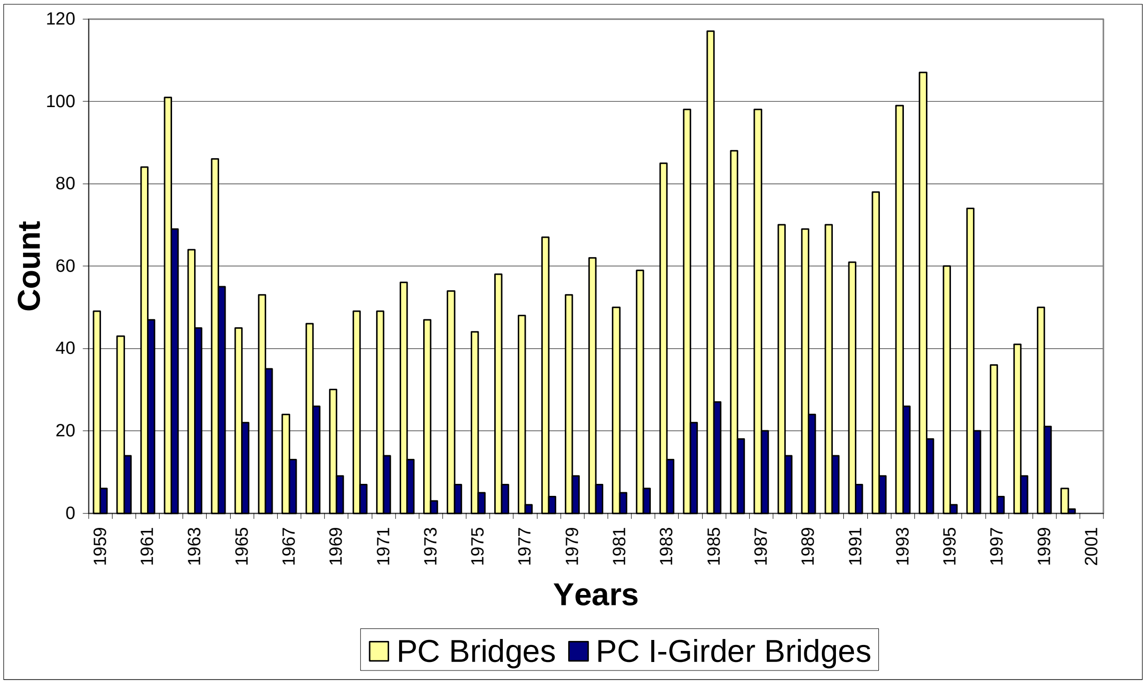


FIGURE 1 Number of prestressed concrete and prestressed concrete I-girder bridges with respect to years.

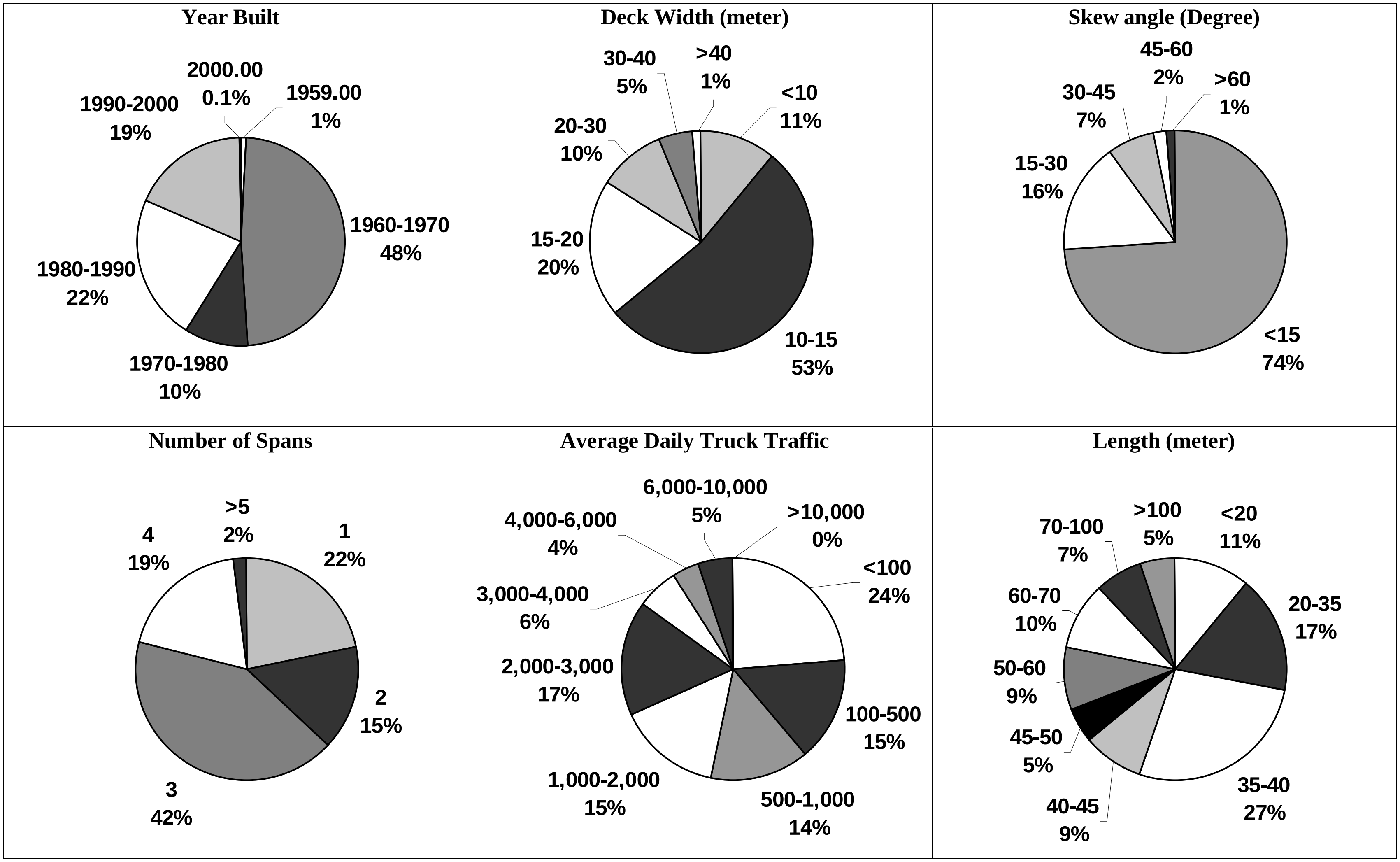


FIGURE 2 Fleet parameters of prestressed concrete bridges.

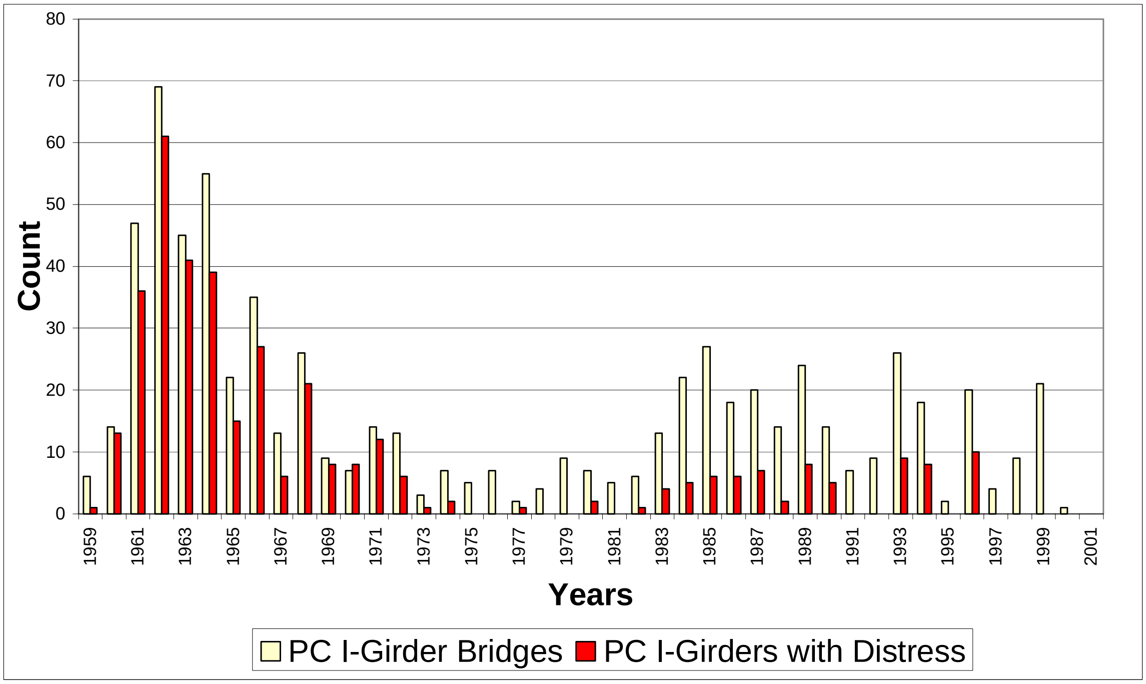


FIGURE 3 Number of prestressed concrete I-girder bridges with distress distributed according to years.

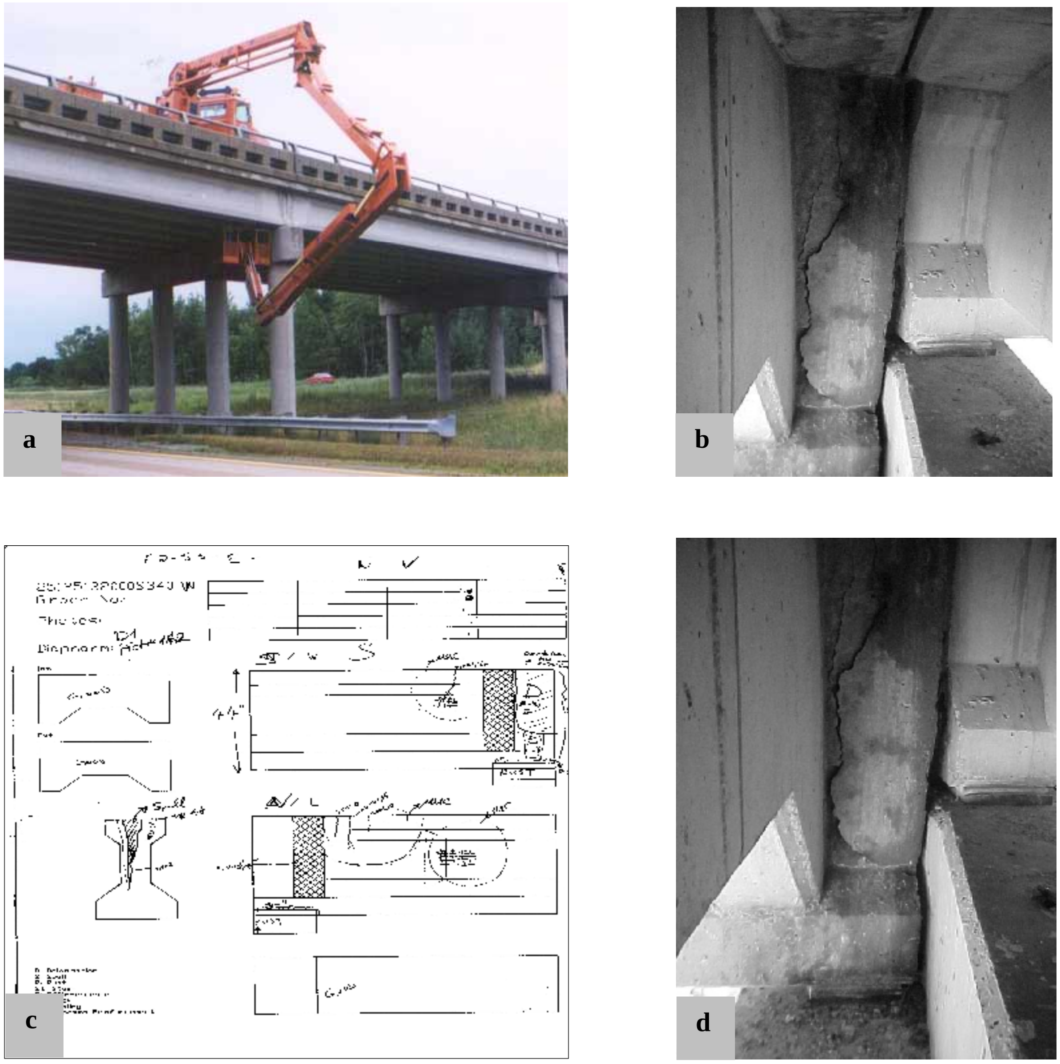
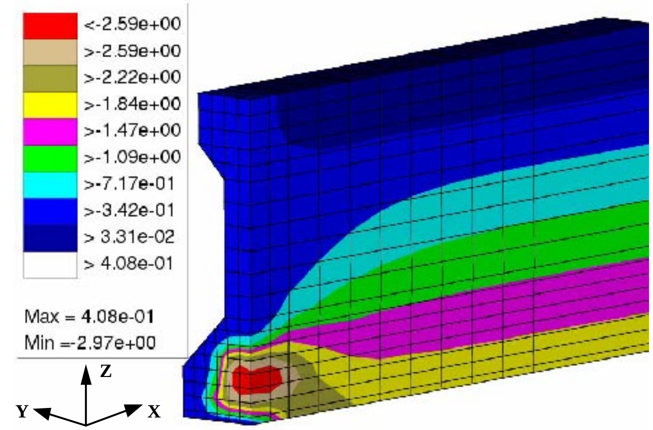
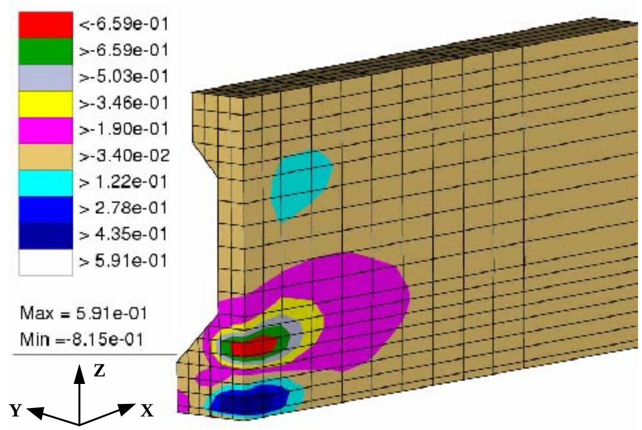


FIGURE 4 (a) General view of the bridge (ID 25132 S340); (b) Condition of beam-ends of adjoining spans with deck; (c) Field inspection form depicting the beam-end condition; (d) Beam-ends with bearings.

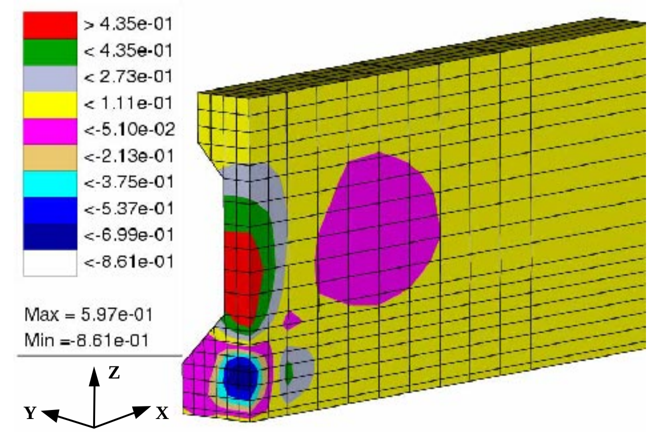
(a) Common cracks near the beam-end



(b) Axial stress-xx (ksi)



(c) Shear stress-xz (ksi)



(d) Axial stress-zz (ksi)

FIGURE 5 (a) Common cracks near the beam-end; (b) Axial stress-xx (ksi); (c) Shear stress-xz (ksi); (d) Axial stress-zz (ksi).

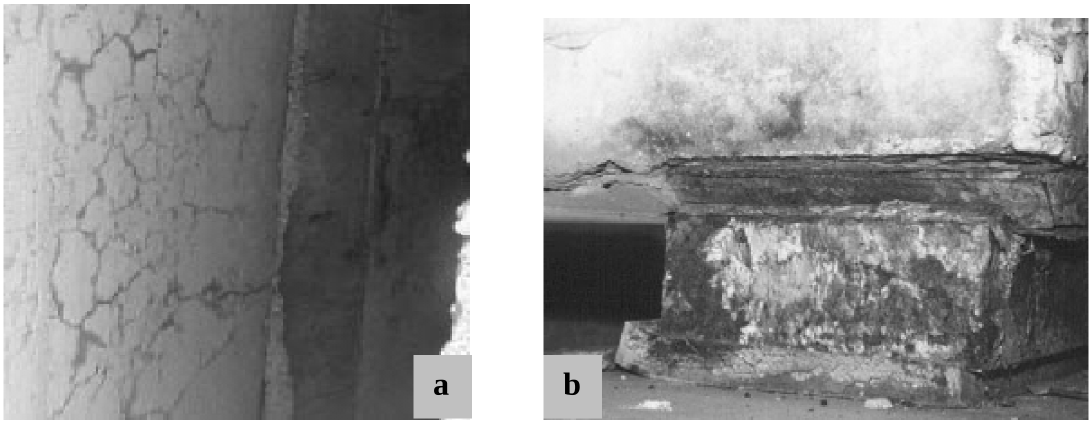


FIGURE 6 (a) Hairline and Mapping cracking; (b) Bearing Condition (Condition state 6).